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13. ABSTRACT

This report was prepared as an aid to wind field analysis. A brief discussion of basic concepts in isogon-isotach analysis is followed by a discussion of methods for determining relative vorticity, divergence and vertical velocity.

Computation examples are included in the appendix.

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THE USE OF ISOGON-ISOTACH CHARTS FOR DETERMINING DIVERGENCE, RELATIVE VORTICITY AND VERTICAL VELOCITY

NAVY WEATHER RESEARCH FACILITY
BUILDING R-48, NAVAL AIR STATION
NORFOLK, VIRGINIA 23511

APRIL 1967

FOREWORD

This report was prepared under NWRF Task 13, "Study and Research of Middle Latitude Maritime Weather Systems" by Mr. Steven H. Cohen, Task Leader, and Dr. J. Robert Stinson, former Chief, Research Division.

The techniques described herein are not likely to be accepted for widespread operational use, owing to the time required for their application. Nevertheless, understanding of certain aspects of the more direct streamline analysis will be enhanced by a thorough appreciation of the relationships between isogon-isotach patterns and relative vorticity, horizontal divergence, and vertical velocity which are discussed in this publication. Fundamental definitions and a general theoretical background of kinematic analysis techniques are contained in the basic report. The appendices provide information on the preparation and use of overlays, computational examples, and the tables used with these techniques.

Application of the techniques presented is in no way restricted to middle latitude usage. Characteristics of the orientation or configuration of isogons and isotachs which provide direct qualitative implications of convergence or vorticity can be applied in any geographical area.

Reviewed and approved on 22 June 1967.

W. L. SOMERVELL, JR.
Captain, U. S. Navy
Officer in Charge
U.S. Navy Weather Research Facility

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INTRODUCTION

The isogon-isotach chart is one of the fundamental forms of windfield analysis. However, because of the time required to prepare the isogon chart and then connect the resultant direction field into the more descriptive streamlines, this chart has had only limited usage in meteorology. Another limiting factor is that the accuracy of the analysis depends so heavily on the spacing of the reports and the skill of the analyst. The primary advantage of the isogon-isotach chart is the quantitative nature of the basic scalar fields. These charts are ideally suited for machine or hand computation of divergence, vorticity and vertical motion. The present paper describes and illustrates hand computational techniques for determining these parameters. It also describes an analytical technique for determining lines of maximum and minimum streamline divergence. Additionally, a method is presented for identifying asymptotes of streamline divergence or convergence, when present.

Direct analysis of the wind field has been practiced in meteorology for many years. V. Bjerknes and the Norwegian school were leaders in developing methods of motion analysis, and made extensive use of the kinematic technique. However, the operational use of isogon-isotach analysis has been limited through the years. The analysis was originally hampered by the inaccuracy and nonavailability of wind reports. Most of the middle-latitude meteorologists felt that pressure measurements were more accurate and less subject to error. Further, the geostrophic wind approximation allowed analysts to obtain a continuous wind field directly from the pressure pattern, and lessened the necessity for reliance upon kinematic analysis techniques.

Historically, isogon analysis has only been used as a first step in producing the streamline chart. An approximate solution to this tedious process was found by drawing streamlines tangent to the wind reports. As a consequence of these factors, operational use of isogon-isotach charts has largely been restricted to tropical regions, where analysis of the dynamic parameters has generally not proven sufficient for operational forecasting purposes. Today, wind observations are more available than other types of upper-air data, particularly at the lower levels. By utilizing the techniques presented in this paper, the meteorologist can develop a comprehensive synoptic analysis for his area of interest on a current basis.

1. DETERMINING RELATIVE VORTICITY AND DIVERGENCE

1.1 Basic Definitions

The horizontal velocity at a given point may be described kinematically by any combination of four components: (1) translation, (2) deformation, (3) divergence (expansion) and (4) vorticity (rotation). Vorticity and divergence are commonly computed by the meteorologist. In mathematical terms, the relative vorticity can be expressed as

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \qquad (1)$$

where u and v are the components of horizontal velocity. Divergence can be written as

$$D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}. \qquad (2)$$

If V describes the velocity and $\propto$ is the angle between the wind direction and an east-west axis, then the horizontal velocity components are:

$$u = V \cos \propto; \quad \text{and} \quad v = V \sin \propto.$$

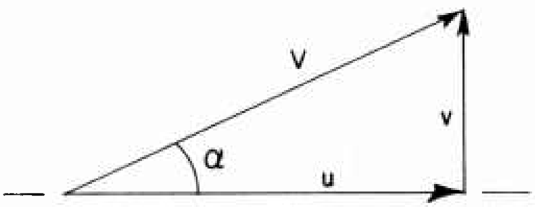

Figure 1.1. Horizontal Velocity Components.

After differentiating u and v with respect to x and y the following relationships are found:

$$\frac{\partial u}{\partial x} = \frac{\partial V}{\partial x} \cos \propto - V \sin \propto \frac{\partial \propto}{\partial x}; \qquad (3)$$

$$\frac{\partial u}{\partial y} = \frac{\partial V}{\partial y} \cos \propto - V \sin \propto \frac{\partial \propto}{\partial y}; \qquad (4)$$

$$\frac{\partial v}{\partial x} = \frac{\partial V}{\partial x} \sin \propto + V \cos \propto \frac{\partial \propto}{\partial x}; \quad \text{and} \qquad (5)$$

$$\frac{\partial v}{\partial y} = \frac{\partial V}{\partial y} \sin \propto + V \cos \propto \frac{\partial \propto}{\partial y}. \qquad (6)$$

In a natural coordinate system positive x is a measure of length along the streamline and is usually denoted as positive s, whereas positive y is a measure of length along the normal to the left of the streamline and is written as positive n. The rate of change of the angle $\propto$ along the streamline $\frac{\partial \propto}{\partial x}$ or $\frac{\partial \propto}{\partial s}$ represents the curvature of the streamline K_s, as illustrated in figure 1.2. The orthogonal curvature $\frac{\partial \propto}{\partial y}$ or $\frac{\partial \propto}{\partial n}$ is defined as K_o and is also illustrated in figure 1.2. The inverse of the curvatures $1/K_s$ and $1/K_o$ are equal in magnitude to R_s and R_o, the streamline and the orthogonal radius, respectively.

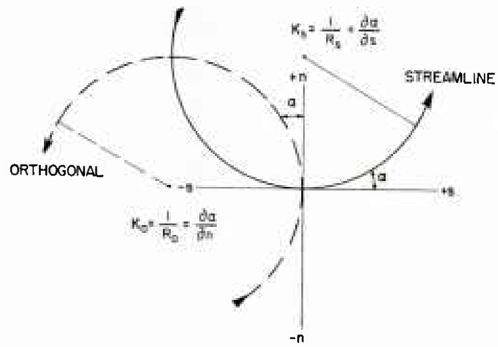

Figure 1.2. Streamline and Orthogonal Relationships.

If the velocity V is considered as having the same direction as the positive s axis, so that the angle $\propto$ is equal to zero, the equations for relative vorticity (the rotation of the earth is not considered) and divergence become:

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \frac{V}{R_s} - \frac{\partial V}{\partial n}; \qquad (7)$$

$$D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{V}{R_o} + \frac{\partial V}{\partial s}. \qquad (8)$$

For graphical methods the equations can be approximated by finite increments as:

$$\zeta = \frac{\Delta v}{\Delta x} - \frac{\Delta u}{\Delta y} = \frac{V}{R_s} - \frac{\Delta V}{\Delta n} \qquad (9)$$

$$D = \frac{\Delta u}{\Delta x} + \frac{\Delta v}{\Delta y} = \frac{V}{R_o} + \frac{\Delta V}{\Delta s}. \qquad (10)$$

The graphical computation of V, $\frac{\Delta V}{\Delta n}$ and $\frac{\Delta V}{\Delta s}$ is rather straightforward. The basic problem in

following such a procedure is a method of determining the radius of curvature for both the streamline and its orthogonal.

1.2 Determining Relotive Vorticity from the Isogon Field

In isolating two consecutive isogons from an isogon-isotach chart it is found that, according to usual convention of spacing isogons at intervals of 30°, any given streamline would change direction from one isogon to the next through an angle of 30°, as illustrated in figure 1.3.

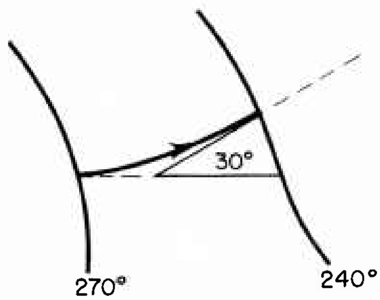

Figure 1.3. Streamline Isogon-Angle Relationship.

Assuming that the rate of change in direction is constant between the two isogons, then the streamline describes a 30° arc of a circle as shown in figure 1.4. By drawing a straight line between the intercept points of any given streamline defined by the isogons, the chord of the 30° arc can be obtained.

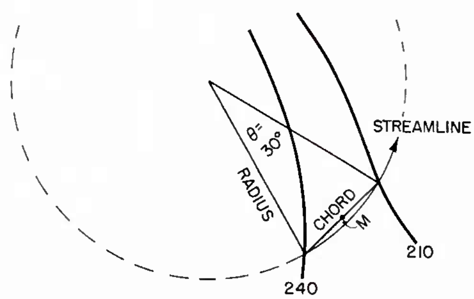

Figure 1.4. The Relationship between Streamline, Streamline Chord and Radius.

From geometry, the chord of a circle is equal to twice the radius of the circle times the sine of half the angle of the arc, written as:

$$C = 2r \sin \tfrac{1}{2}\theta \qquad (11)$$

where θ = arc angle. Now in this case,

$$\sin \tfrac{1}{2}\theta = \sin \tfrac{1}{2}30^\circ = 0.25882,$$

and

$$r = \frac{C}{2\,(0.25882)} = 1.93\ C.$$

So, in order to find the radius, we first determine the chord of the streamline, measure its length and mulitply by the factor 1.93. The same geometry will apply to any other isogon interval; only the multiplication factor would be changed.

Standard convention is maintained for the sign of the radius (positive for cyclonic curvature and negative for anticyclonic curvature). If, along the direction of the flow, the isogon values are increasing, the movement is clockwise and anticyclonic. If, on the other hand, the isogon values are decreasing, the movement is counterclockwise and cyclonic.

Care must be taken in the construction of the streamline chord so that it maintains the proper orientation with respect to the streamlines. Simple thumb rules for the construction are as follows:

1. Add 15° to the chord direction at the left hand isogon-streamline intercept, provided that the isogon values are increasing downstream (fig. 1.5).
2. Subtract 15° if the isogon gradient is decreasing downstream (fig. 1.6).

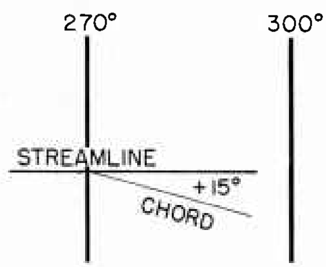

Figure 1.5. Positive Angle Chord Orientation.

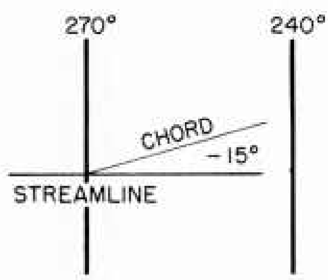

Figure 1.6. Negative Angle Chord Orientation.

This 15° is the angle between the arc and the chord at the intercept of a 30° sector of a circle, as illustrated in figure 1.7.

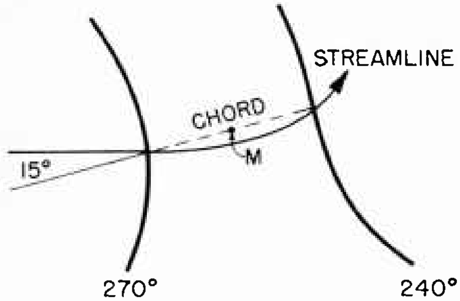

Figure 1.7. The Angle Relationship between Streamline and Chord.

The use of this thumb rule can be facilitated by use of a computation overlay. An overlay for this purpose is described in appendix A. It is now possible to compute the relative vorticity at a given point by the following steps:

1. Starting with a base isogon such as 270°, arbitrary chord lines are drawn between consecutive isogons.
2. The midpoints (M) along these lines are marked. At the midpoint, the direction of the chord and the streamline are identical.
3. The chordal distance between isogons is measured in nautical miles, and the speed (in knots) at the midpoint is read. For this measurement it is assumed that the speed at the chord midpoint represents the speed at the corresponding streamline point. Enter table C.1 (appendix C) using the wind speed and chordal distance to obtain the first term V/R_s of the relative vorticity equation (9).
4. The wind shear normal to the chord is computed by determining the difference in velocity between points 2½° of latitude = 150 nautical miles apart (1¼° on either side of the chord) along a line normal to the chord. The shear term is obtained by reading its corresponding value from table 1. The sign of the shear term of the relative vorticity equation is determined by the increase or decrease of velocity with distance to the left of the flow. Increasing velocity indicates anticyclonic wind shear and is positive. Decreasing velocity is cyclonic shear and is negative.
5. Add the curvature and shear terms algebraically to obtain the relative vorticity at the point in question. In practice, it has been found useful to plot these points and analyze the field on acetate or tracing paper placed over the isogon-isotach analysis.

Table 1. Conversion of V, u or v to $\frac{\Delta V}{\Delta s}, \frac{\Delta V}{\Delta n}, \frac{\Delta u}{\Delta x}, \frac{\Delta u}{\Delta y}, \frac{\Delta v}{\Delta x}$ *and* $\frac{\Delta v}{\Delta y}$ *For Distance Interval of 2½° = 150 Nautical Miles (Values × 10^{-5} sec.$^{-1}$)*

Part One

V, u, v (Knots)

V, u, v	1	2	3	4	5	6	7	8	9	10
$\frac{\Delta(\ )}{\Delta(\ )}$	0.185	0.370	0.556	0.741	0.926	1.111	1.296	1.481	1.667	1.852

V, u, v	12	14	16	18	20	22	24	26	28	30
$\frac{\Delta(\ )}{\Delta(\ )}$	2.223	2.593	2.963	3.333	3.704	4.074	4.444	4.815	5.185	5.556

Part Two

V, u, v (Meters per Second)

V, u, v	1	2	3	4	5	6	7	8	9	10	11
$\frac{\Delta(\ )}{\Delta(\ )}$	.360	.721	1.081	1.441	1.802	2.162	2.522	2.882	3.243	3.604	3.964

V, u, v	12	14	16	18	20	22	24	26	28	30
$\frac{\Delta(\ )}{\Delta(\ )}$	4.324	5.045	5.766	6.486	7.207	7.928	8.649	9.369	10.090	10.810

1.3 Determining Divergence from the Isogon Field

The equation for divergence in natural coordinates was given in equation (10) as:

$$D = \frac{V}{R_o} + \frac{\Delta V}{\Delta s} .$$

In this equation, $\frac{\Delta V}{\Delta s}$ represents the wind increase (speed divergence) or decrease (speed convergence) along a streamline, and R_o is the radius of curvature of the orthogonal to the streamline. Since the streamline and its orthogonal function are perpendicular to one another at every point in the field, it follows that the radii and the chords are mutually perpendicular. Following this reasoning, we construct the chord of a given streamline between two consecutive isogons, as was

shown in figure 1.4. Next, a perpendicular line representing the chord of the orthogonal function is drawn through the midpoint (M) of the streamline chord. M can now be chosen as the point of computation for either relative vorticity or divergence. This is also an approximation in the sense that the midpoints of the streamline and the orthogonal chords do not necessarily coincide. However, M represents the point at which the two chords are perpendicular as illustrated in figure 1.8.

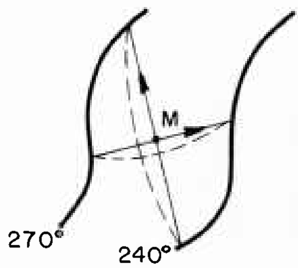

Figure 1.8. The Orthogonal Chord.

The direction of the orthogonal flow will be to the left of the streamline flow. That is to say, if the streamline flow lies along the positive s axis, the orthogonal flow will lie in the direction of the positive n axis. From the direction of the orthogonal chord the proper value of the orthogonal isogon can be obtained and the sign of the curvature determined. For example, assume that all the steps through the construction of the orthogonal chord have been completed, and the direction of the orthogonal flow at the 270° isogon is either 180° or 360°, while along the 240° isogon the flow is either 150° or 330°, as shown in figure 1.9. The direction of the streamline

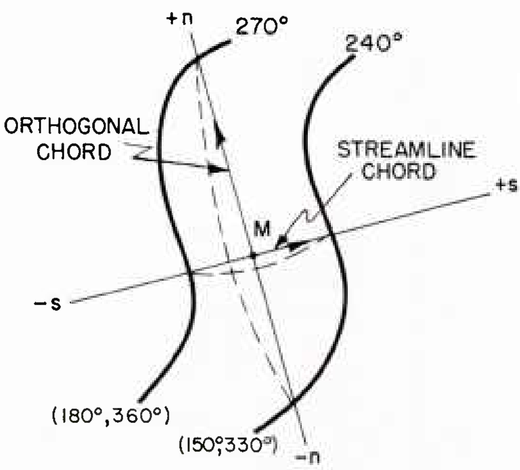

Figure 1.9. Relationship of Streamline and Orthogonal Chords.

chord at M represents flow along the positive s axis so that the direction of the orthogonal chord must be to its left, along the positive n axis. The value of the 270° isogon for orthogonal flow must be 180°, while the value of the 240° isogon changes to 150°. As illustrated in figure 1.10, the streamline curvature at point M is positive or cyclonic, while the orthogonal curvature is anticyclonic or negative.

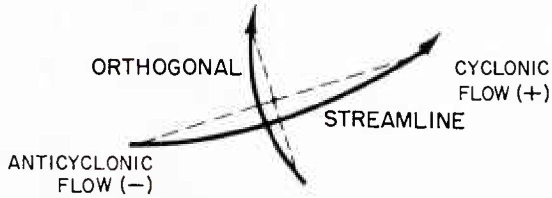

Figure 1.10. Orthogonal Curvature Sign Convention.

Once the orthogonal chord has been drawn and the sign of the curvature determined, the steps in evaluating the divergence are similar to those for determining relative vorticity, with some points of difference. First, $\frac{\Delta V}{\Delta s}$ is taken *normal to the orthogonal chord*; the direction of its increase or decrease is always taken in the direction of the streamline flow or *to the right of the orthogonal flow*. It must be remembered that this term, physically, is not a shear but represents speed divergence or convergence along a streamline. For example, consider the case shown in figure 1.11.

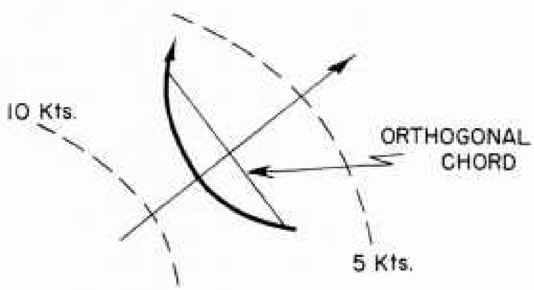

Figure 1.11. Speed Convergence.

The orthogonal curvature is anticyclonic, representing directional convergence of the streamline, and therefore the sign would be negative. The value of $\frac{\Delta V}{\Delta s}$ is also negative, representing speed convergence along the streamlines. The two terms of the divergence equation are both negative (convergence) and would be added algebraically.

1.4 An Alternative Method for Computing Relative Vorticity and Divergence

A second method for computing relative vor-

ticity and divergence makes use of the equations in their finite difference form (equations 9 and 10):

$$\zeta = \frac{\Delta v}{\Delta x} - \frac{\Delta u}{\Delta y};$$

and

$$D = \frac{\Delta u}{\Delta x} + \frac{\Delta v}{\Delta y}.$$

The u and v components of velocity can be computed almost directly from an isogon-isotach chart.

By using the conventional isogon interval of 30°, each streamline along a given isogon will form either a 0°, 30°, 60°, or 90° angle with the east-west axis. Therefore, the components u and v will be equivalent to the velocity V times the factor 0.000, .500, .866 or 1.000 (see fig. 1.12).

For example, taking the intersection of the 300° isogon and the 10 knot isotach, we note that the velocity vector at the intersection forms a 30° angle with the east-west axis, and the components are:

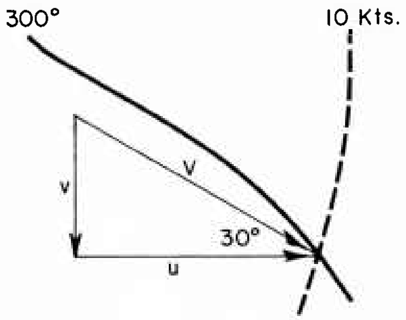

Figure 1.12. u and v Components for 300°, 10 Knots.

$$u = V(\cos 30°) = 10\,(.86603) = 8.6603\ kt.$$

and

$$v = -V(\sin 30°) = -10\,(.50000) = -5.0000\ kt.$$

α	0°	30°	60°	90°
cos	1.00	.866	.500	0
sin	0	.500	.866	1

The signs of u and v are determined by the quadrant in which the isogon lies according to standard notation, as illustrated in figure 1.13.

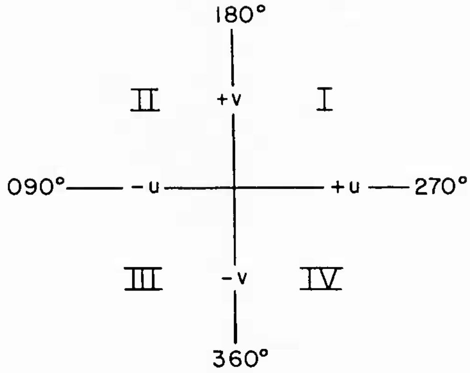

Figure 1.13. u and v Component Sign Convention.

In practice, the relative vorticity may be computed in the following steps:

1. The intersections of the analyzed isotachs and the isogons are chosen as points of computation for u and v. The values of both the isogon and isotach are entered in table 2, and the u and v components are obtained. These components may be plotted at each point on acetate or tracing paper with the use of two colors — preferably, black for the u component and red for the v component.
2. Tracing paper is then placed over the plotted base chart, and the u component chart is drawn for chosen intervals utilizing the u values at each intersection point.
3. A new sheet of tracing paper is placed over the base chart, and the v component chart is then analyzed for the chosen intervals.

   There are a number of methods which may be used in the determination of $\frac{\Delta v}{\Delta x}$ and $\frac{\Delta u}{\Delta y}$. One method is to use an overlay grid whose size has been previously determined by the analyst. The values of Δu or Δv can then be established in any one of four directions from a given grid point and through any desired distance.
4. In the case of relative vorticity, the east-west grid lines are used in determining $\frac{\Delta v}{\Delta x}$. The grid is placed over the v component chart, and the values of v are estimated at points $1\frac{1}{4}°$ of latitude = 75 nautical miles to the west and $1\frac{1}{4}°$ of latitude to the east of the given grid point. The values of v are subtracted, west from

east, and the difference is entered in table 1 to find $\frac{\Delta v}{\Delta x}$.

5. The same procedure is followed for the u component. The values of u are determined at points $1\frac{1}{4}°$ of latitude on either side of the grid point. In this case the north-south grid line is used. The difference is found by subtracting south from north and entering the result in table 1 to determine $\frac{\Delta u}{\Delta y}$.
6. $\frac{\Delta u}{\Delta y}$ is subtracted from $\frac{\Delta v}{\Delta x}$ at each grid point, and the resultant relative vorticity field is analyzed.

Table 2. u and v Components for Standard Isogon-Isotach Intervals

ISOGON		V WIND SPEED (Knots)			
		5	10	15	20
360	u =	0.00	0.00	0.00	0.00
	v =	-5.00	-10.00	-15.00	-20.00
030	u =	-2.50	- 5.00	- 7.50	-10.00
	v =	-4.33	- 8.66	-12.99	-17.32
060	u =	-4.33	- 8.66	-12.99	-17.32
	v =	-2.50	- 5.00	- 7.50	-10.00
090	u =	-5.00	-10.00	-15.00	-20.00
	v =	0.00	0.00	0.00	0.00
120	u =	-4.33	- 8.66	-12.99	-17.32
	v =	+2.50	+ 5.00	+ 7.50	+10.00
150	u =	-2.50	- 5.00	- 7.50	-10.00
	v =	+4.33	+ 8.66	+12.99	+17.32
180	u =	0.00	0.00	0.00	0.00
	v =	+5.00	+10.00	+15.00	+20.00
210	u =	+2.50	+ 5.00	+ 7.50	+10.00
	v =	+4.33	+ 8.66	+12.99	+17.32
240	u =	+4.33	+ 8.66	+12.99	+17.32
	v =	+2.50	+ 5.00	+ 7.50	+10.00
270	u =	+5.00	+10.00	+15.00	+20.00
	v =	0.00	0.00	0.00	0.00
300	u =	+4.33	+ 8.66	+12.99	+17.32
	v =	-2.50	- 5.00	- 7.50	-10.00
330	u =	+2.50	+ 5.00	+ 7.50	+10.00
	v =	-4.33	- 8.66	-12.99	-17.32

In the computation of divergence, steps 1 through 3 are identical to that for the computation of relative vorticity. However, the remaining steps are altered as follows:

4. The grid is placed over the v component chart, and the values of v are estimated at points $1\frac{1}{4}°$ of latitude to the north and the south of the given grid point. The values of v are subtracted and the difference is entered in table 1 to determine $\frac{\Delta v}{\Delta y}$.
5. Using the overlay grid and the u component chart, the values of u are determined at points $1\frac{1}{4}°$ on either side of the grid point. An east-west grid line is used in this case. The difference is entered in table 1 to determine $\frac{\Delta u}{\Delta x}$.
6. The value of $\frac{\Delta v}{\Delta y}$ is added to $\frac{\Delta u}{\Delta x}$ at each grid point to give the divergence, and the resultant divergence field is analyzed.

1.5 Determining Vertical Velocity from the Divergence Field

Once divergence charts have been analyzed for all desired levels, the vertical velocity at any point may be computed by the kinematic method. If the height (Z) is measured in meters, and the vertical velocity (w) is in meters per second, the equation for w at a given level is:

$$w_2 = +\frac{\rho_1}{\rho_2} w_1 = \frac{\rho_2 - \rho_1}{2\rho_2} \left\{ \frac{(\nabla_H \cdot \underline{V})_2 + (\nabla_H \cdot \underline{V})_1}{2} \right\} Z_2 - Z_1 \qquad (12)$$

where the subscript 2 denotes the level in question and the subscript 1 denotes the next lowest computational level.

ρ = the density of the air (mass per unit volume), $\nabla_H \cdot \underline{V}$ = the horizontal divergence (per time).

Since the horizontal divergence values at any given level are computed for a point, the vertical velocity will also be valid only for that point in the horizontal. It is recommended that a grid be drawn according to the map scale and the particular need of the analyst. The divergence values can then be determined at each level for the grid points. The average horizontal divergence may be found at any point by adding the divergence values at the base and the top of the layer algebraically and dividing by 2.

1.6 Directional Divergence

The determination of directional divergence from streamline analysis has always been a rather subjective process. However, much of this subjectivity can be eliminated by the direct use of isogon analysis. The strength of the maximum convergence or divergence is related to the spacing of the isogons in the sense that the closer the isogon interval occurs, the stronger the convergence or divergence will be. One method of describing the convergence from the isogon field is by the construction of an isogon deviation (ID) field.

A given streamline forms an angle with an isogon that will vary between 0° to 90°. When a

streamline is parallel to the isogon over any finite length, it represents an asymptote of directional convergence or divergence. If the streamline and the isogon are perpendicular, the streamline represents a line along which there is neither streamline convergence nor divergence. For illustrative purposes, consider a closed 270° isogon that has the symmetric form of a circle. The streamlines of the field will be tangent to this isogon at two points and perpendicular at two points as illustrated in figure 1.14.

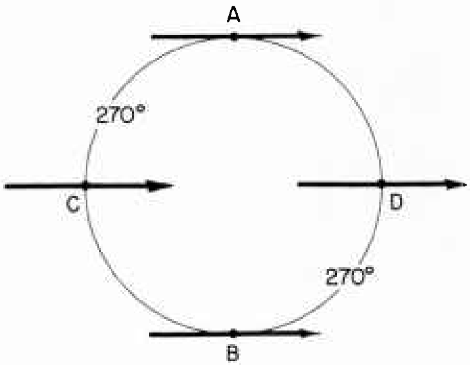

Figure 1.14. Streamline-Isogon Angle for a Circular Isogon.

The directional field enclosed by the isogon must be either greater or less than 270°. Consider first the case in which the values are less than 270° (for illustration the value at the exact center of the circle in figure 1.15 is taken as 240°).

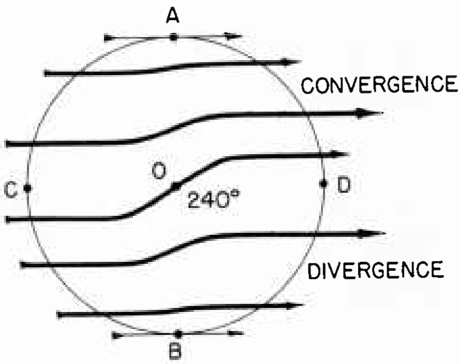

Figure 1.15. Convergence-Divergence Patterns for Values Greater than 270°.

The streamlines cross the isogon circle from the left at a direction of 270°, turning through some small angle between 270° and 240° and departing at a direction of 207° on the right. Point A, which is a parallel point between the streamline and the isogon, represents a point on a line of maximum convergence that also goes through the center 0; point B, the opposite parallel point, represents a point on a line of maximum divergence which also passes through the center 0. Points C and D, the perpendicular points, represent the delineation between directional convergence and divergence and are on a line of minimum divergence which also passes through the center 0.

These four points may also be labeled according to the streamline-isogon angle. Point A would be -0 (- for convergence, 0 for tangency); point B is +0 (+ for divergence). Points C and D would be labeled as 9 (there would be no sign since they are neither points of convergence nor divergence, and 9 indicates an angle of 90°). If the directional field were greater within the enclosed area, A would be labeled +0, B would be -0, and points C and D would remain unchanged. Figure 1.16 illustrates points A, B, C and D for the cardinal positions.

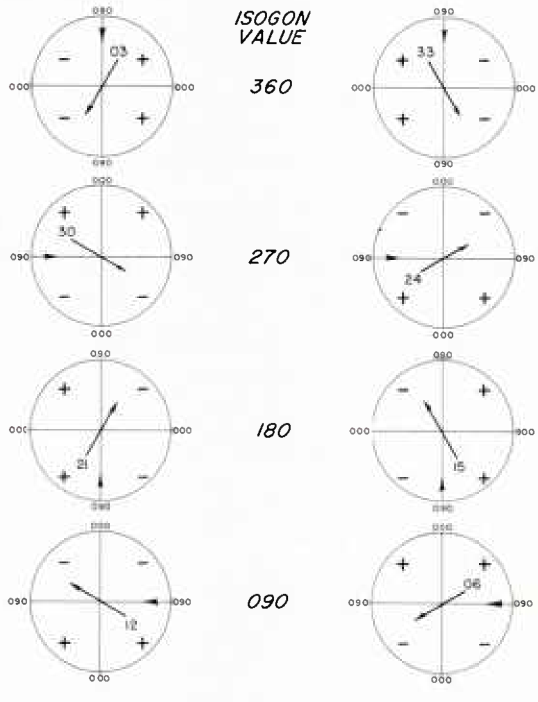

Figure 1.16. Closed Isogon Patterns Related to Streamline Divergence and Convergence.

Within a closed isogon, then, the isogon deviation (ID) field will geometrically have both convergent and divergent areas. For the isogon field in general, the neighboring isogons must be considered in order to determine whether the streamlines are converging or diverging. In the case when the isogon is parallel to the direction it represents, if the isogon to the right of the wind vector decreases, the streamline field is convergent (-) (see fig. 1.17).

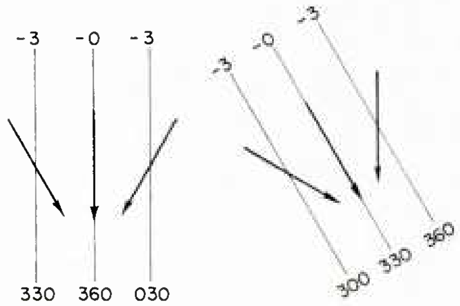

Figure 1.17. Divergence and Isogon Gradient Relationships.

If the isogon value to the right of the wind vector increases, the streamline field is divergent (+) (see fig. 1.18).

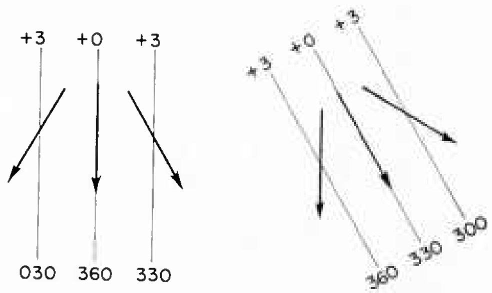

Figure 1.18. Convergence and Isogon Gradient Relationships.

As the isogons approach the 90° deviation, the problem is more difficult because the field reverses sign; but around the 0 deviation line the field is symmetrical.

An isogon deviation (ID) chart can easily be drawn by making use of a scale overlay system in order to ascertain the angle made between streamline and isogon. The recommended system is shown in figure 1.19. The scales are constructed for isogon increments of 15° and contain angle increments of 30°. It should be noted that one scale applies for an isogon and its reciprocal.

The scales can be made into a transparency and used as an overlay or placed under a map and read with the aid of a light table. The proper scale is chosen to match a given isogon, and the crosshair point is run along the isogon keeping N pointed due north. When the isogon is parallel to a given angle, the point is marked and labeled with the appropriate ID value. The sign of the point is determined by the rules stated earlier. Consider, as an example, two points along the 270° isogon (fig. 1.20). At point A, the scale for the 270° isogon indicates that the angle between the streamline and the isogon is zero, while at point B the angle is 30°. The signs of both A and B are positive (+), since the isogon values are increasing to the right of the wind vector. If the situation were reversed between the 300° and 240° isogons, the sign of points A and B would be negative (-).

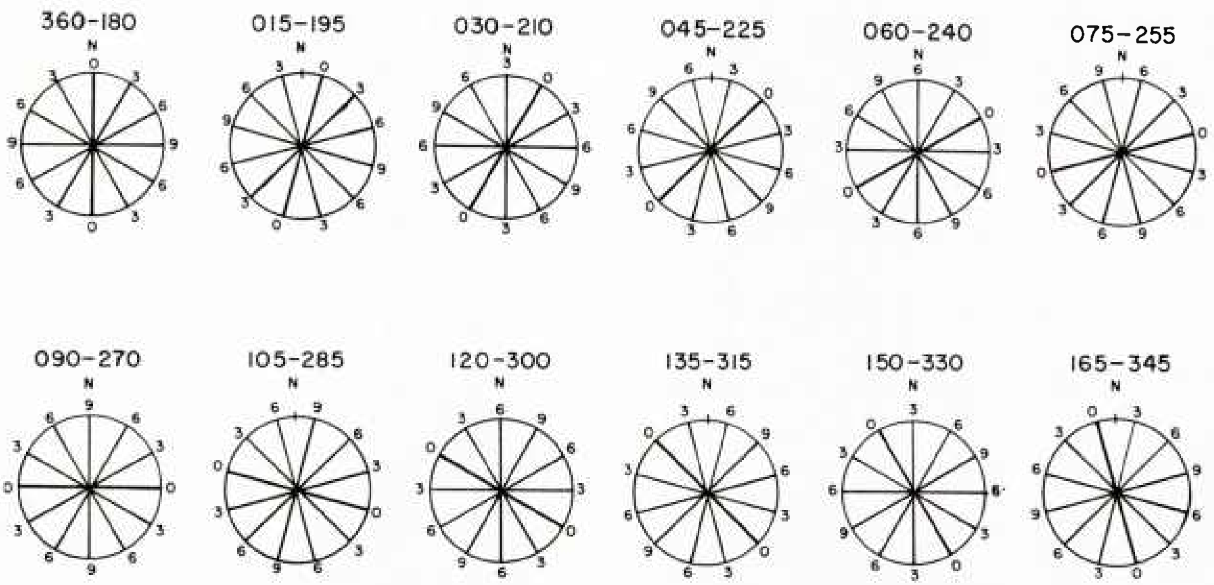

Figure 1.19. Isogon Deviation Scales Used in the Construction of the Isogon Deviation Chart.

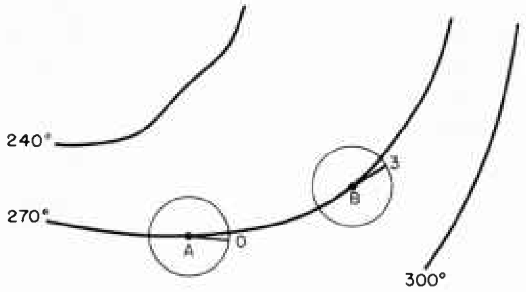

Figure 1.20. Use of Isogon Deviation Scales.

Once the points are determined for each isogon, the analysis is straightforward. It is primarily a matter of connecting the points of equal value, as illustrated in figure 1.21.

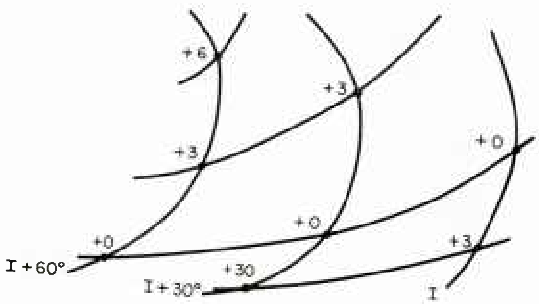

Figure 1.21. Isogon Deviation Analysis.

The only singular points that occur should be in the geometrical center of a closed isogon. However, the iso-IDs, lines of constant isogon deviation, may be skewed, as it is possible to have more than one closed isogon in a group about a point. For instance, if a 300° isogon enclosed a 270° isogon a pattern such as seen in figure 1.22 could result. The 9 iso-IDs would, then, separate the areas of directional convergence, while the 0 iso-IDs indicate asymptotes of complete directional convergence or divergence. The area enclosed by ± 3 iso-IDs consists of zones of maximum directional convergence or divergence. The areas between ± 3 and ± 6 iso-IDs represent zones of weaker divergence or convergence while the area between ± 6 and 9 iso-IDs encompasses an area of very little directional convergence or divergence. As can be seen, these zones are all relative in strength to one another, and the actual value of convergence or divergence would be proportional to the width of the ID zones.

The full meteorological implications of an ID chart have yet to be explored. One attempt has been made to correlate areas of maximum directional convergence or divergence with occurrences of clear air turbulence [5]. Some of the results are shown in table 3. The numbers are somewhat deceptive, because all the areas were considered equal. This gives a much lower weight factor to the areas ± 3 to 0 since, on the average, these zones covered only 10 to 20 percent of the map.

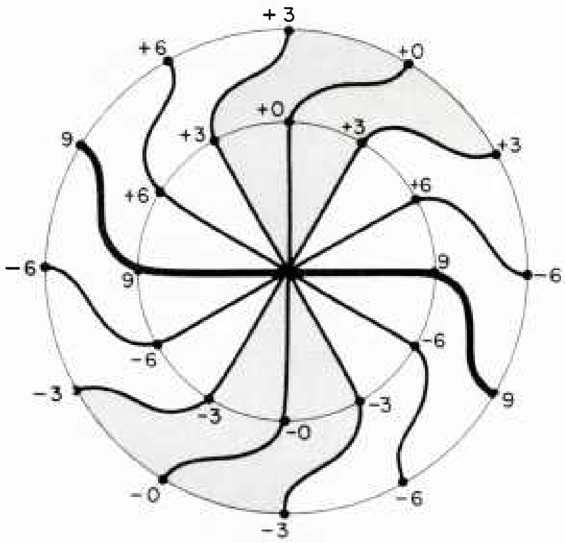

Figure 1.22. Isogon Deviation Analysis for a Circular Isogon Pattern.

Table 3. Distribution of CAT in Relation to Isogon Deviation and Wind Speed (November - December 1963).

WIND SPEED (MPS)	ISOGON DEVIATION (DEGREES)						
	0° +30°	+30° +60°	+60° +90°	-90° -60°	-60° -30°	-30° -0°	
0 - 10							
10 - 20	27	6				7	40
20 - 30	15	32	28	13	11	17	116
30 - 40	12	9	4	6	7	18	56
40 - 50	15	10	6	3	14	19	67
50 - 60	7	5	5	3			20
60 - 70	5	5	4	5	1		20
70 - 80			1	1		1	3
80 - 90							
90 - 100							
	81	67	48	31	33	62	

2. CONCLUSION

The isogon-isotach chart, with its derivative fields, presents a fairly complete kinematic analysis system. It is hoped that a future program, now being studied by NWRF, will enable the meteorologist to have a compatible graphical-computer analysis and, eventually, a forecasting system using Kinematic Techniques.

REFERENCES

1. GODSKE, C. L., T. BERGERON, J. BJERKNES, and R. C. BUNDGAARD. *"Dynamic Meteorology and Weather Forecasting."* *Boston: American Meteorological Society.* pp. 196-215, 1957.

2. HALTINER, G. J. and F. L. MARTIN. *"Dynamical and Physical Meteorology."* *New York City: McGraw-Hill Book Company, Inc.* pp. 316-317, 1957.

3. PALMER, C. E., C. W. WISE, L. J. STEMPSON, and G. H. DUNCAN. *"Tropical Meteorology."* *Air Force Surveys in Geophysics, Bedford, Mass.: Air Force Cambridge Research Center.* pp. 61-99, September 1955.

4. PETTERSSEN, S. *"Weather Analysis and Forecasting, Vol. 1, Motion and Motion Systems."* *New York City: McGraw-Hill Book Company, Inc.*, pp. 21-44, 1956.

5. STINSON, J. R. and S. H. COHEN. *"Use of Isogon-Isovel Charts and the Isogon Deviation Field in Forecasting Atmospheric Turbulence."* *Unpublished Manuscript, U. S. Navy Weather Research Facility.* 1965.

APPENDIX A
COMPUTATIONAL OVERLAY FOR R, V AND ΔV

A.1 Overlay Design

This overlay has been designed to allow rapid calculation of the orientation and length of the streamline and streamline orthogonal chords and the magnitude of the shear and speed divergence-convergence terms. It consists of three basic parts (fig. A.1):

1. *The Chordal Circle* Designed to allow proper orientation of both the streamline and the orthogonal chord, it consists of a circle divided into 12 equal parts. Each portion represents an arc of 30°. There is also a cut out portion of the circle that is used for drawing the chord. This cut out triangle is based on an angle of 15° which is the angular difference of the chord from the streamline at the isogon in question.
2. *The Distance Scales* This part contains distance markers based upon the map projection, scale and latitude. The scales shown on the sample overlay are arbitrary and may be replaced by the analyst.
3. *The Radius Circles* These circles are based upon latitude and map projection. The radii of the circles are 75 nautical miles, or 1¼° of latitude. The circle is divided into quadrants. Three of the quadrants are labeled by letter — C, D and V. There are marker arrows in the direction of C and D. The radius latitude is indicated within each circle.

A.2 Chordal Orientation and Lenght

1. Using the value of the isogon in question, line up the chordal circle with the center point on the given isogon and the corresponding radius line oriented due south.
2. If the value of the termination isogon (the isogon at the opposite end of the chord) is higher in value than the reference isogon, the line L is used for orientation. If the value of the termination isogon is smaller, the line S is used.
3. The length is measured by the appropriate scale located along the side of the overlay.

A.3 Shear

1. The shear is found by placing the midpoint of the radius circle marked with the value closest to the actual latitude upon the point M (care must be taken to insure that the latitude circles are of the proper scale).
2. The radius marked C is placed along the chord in the direction of the flow. The difference in velocity is then taken between end points of the line D and V.
3. The sign of the shear is positive if the velocity decreases in the direction toward point D, and it is negative if the velocity increases in the direction of D.

A.4 Speed Divergence - Convergence

1. The radius C is lined up along the orthogonal chord in the direction of the orthogonal. The difference in velocity is then read between the points D and V.
2. If the velocity is increasing toward point D, the sign is positive and indicates speed divergence. If, on the other hand, the velocity is decreasing in the direction of point D, the sign is negative and speed convergence is indicated.

   Divergence may be computed by adjusting the overlay clockwise 90° or by relabeling the isogon values in accordance with table A.1.

Table A.1. Conversion Between Streamline Isogons and Their Orthogonals.

Streamline	.360	.330	.300	.270	.240	.210	.180	.150	.120	.090	.060	.030.
Orthogonal	.270	.240	.210	.180	.150	.120	.090	.060	.030	.360	.330	.300.

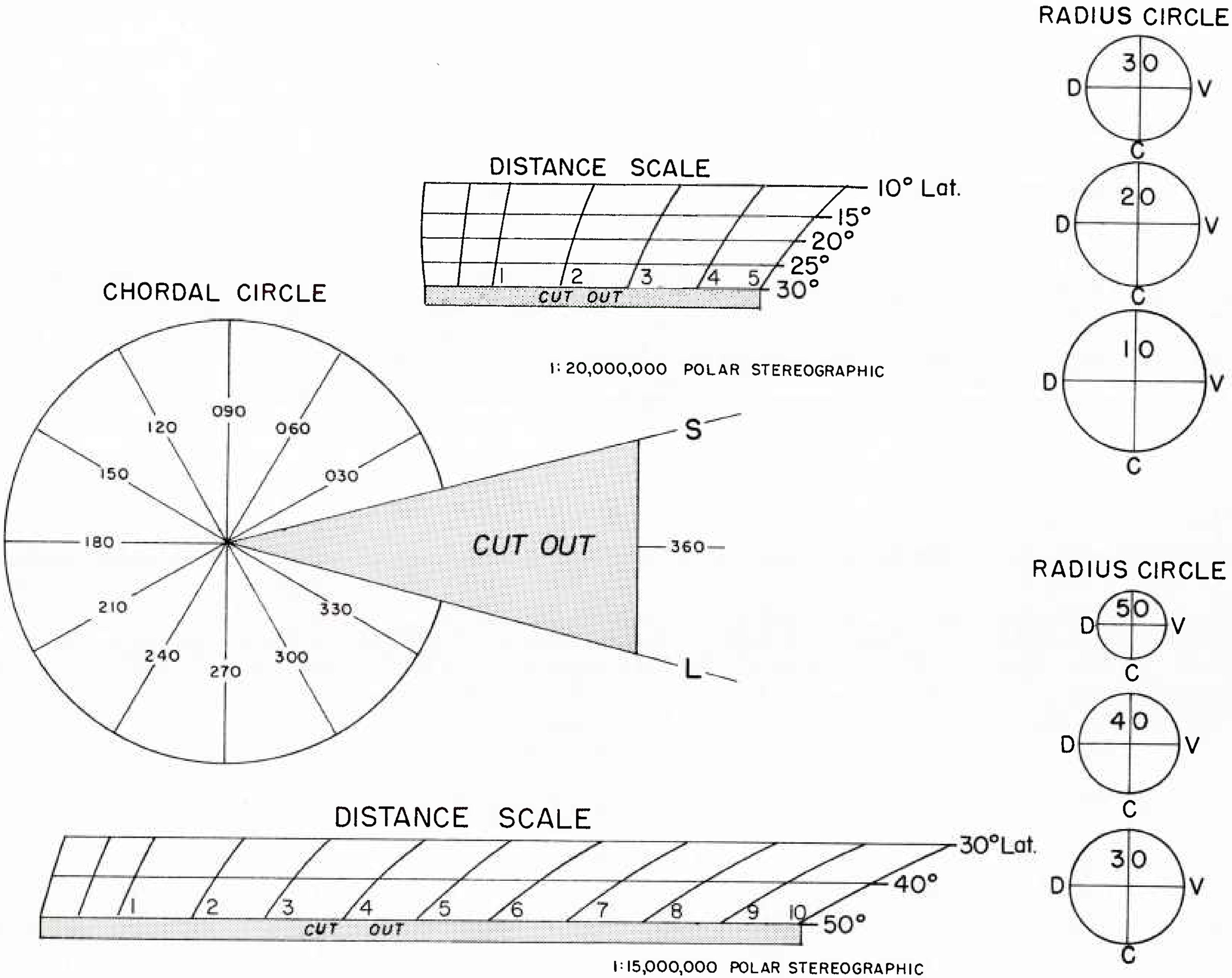

Figure A.1. Computation Overlay.

APPENDIX B
COMPUTATION EXAMPLES

For illustrative purposes, the 500-mb. isogon-isotach analysis for November 29, 1963 was selected as an example (fig. B.1). During the 24 hours following the time of this chart, an upper-level trough deepened rapidly in the vicinity of the Ohio River Valley and expanded southward into the Carolinas. Two separate surface *low* centers (fig. B.2) appeared to merge and deepen during the period. The lowest central pressure dropped from approximately 1004 mb. at 0600Z on the 29th of November to 977 mb. at 0600Z on 30th of November — a decrease of 27 millibars in a 24-hour period.

B.1 Synoptic Situation

The 500-mb. isoheight analysis (fig. B.1) shows a trough over Lake Michigan extending southward into Louisiana. Cold air was pushing in behind the trough with the -30° C. isotherm as far south as Missouri.

The 500-mb. isogon-isotach analysis, shown in figure B.3, shows the strongest concentration of isogons to be located over eastern Missouri and southern Illinois. An isotach minimum of 25 meters per second was also located over this region.

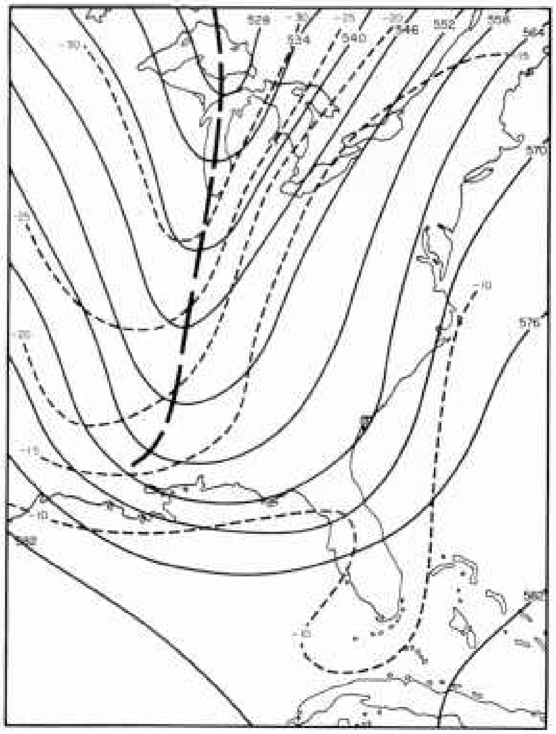

Figure B.1. 500-mb. Isoheight Analysis, 1200Z 29 November 1963.

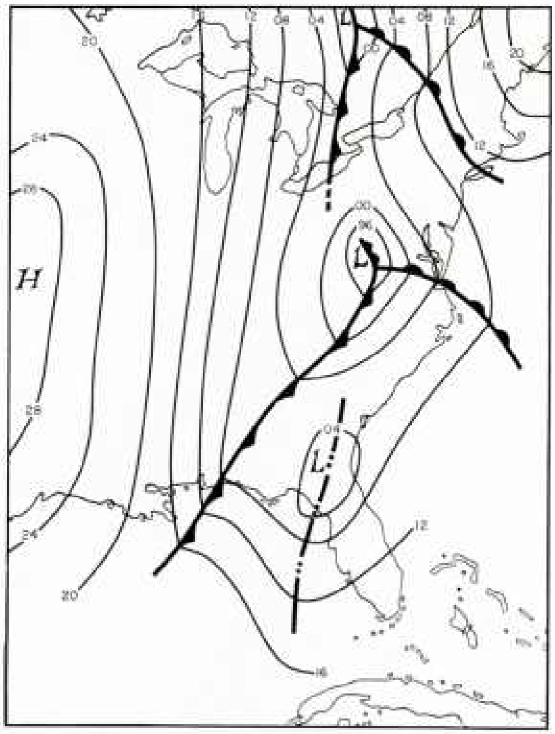

Figure B.2. Surface Analysis, 1200Z 29 November 1963.

B.2 Examples of Relative Vorticity Computations

1. For convenience a piece of tracing paper is placed over the 500-mb. isogon-isotach chart. Computation points are chosen and numbered. In practice, it is convenient to choose midpoints at the intersection of any streamline chord and the isotach nearest the geometric center of an isogon interval, as illustrated in figure B.3.
2. Chords are drawn between isogons as shown in figure B.4. Arrows are placed on the chords to show the direction of the flow. This procedure aids in determining the sign of the radius.
3. Distance is measured from the end points of the chord by using a computational overlay such as shown in appendix A.

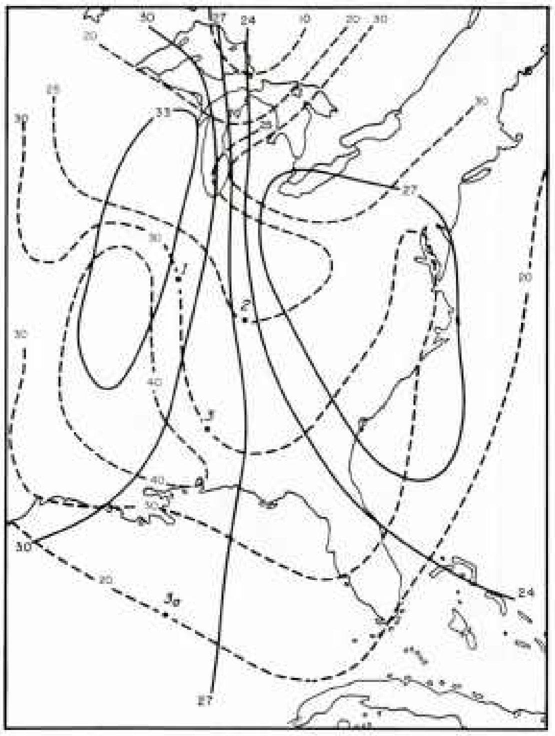

Figure B.3. 500-mb. Isogon-Isotach Chart, 1200Z 29 November 1963.

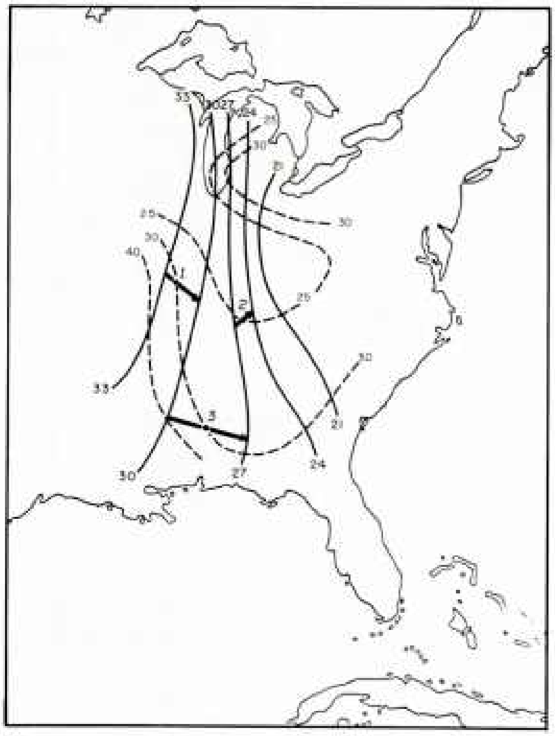

Figure B.4. Orientation of Streamline Chords.

This measurement may be accomplished also by using the scale measurement of the particular map. The chordal distances and the midpoint speeds are entered on a worksheet for computational purposes.

($\zeta \times 10^{-5}$ sec.$^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	$-\Delta V$ (m./sec.)	$\frac{-\Delta v}{\Delta n}$ (1/sec.)	ζ
1	100	30				
2	60	25				
3	180	30				

4. Using the direction arrows for step 2, the sign of the $\frac{V}{R}$ term is entered on the worksheet. For point 1 in the example, the direction change between the two isogons is from 330° to 300°, which is counter-clockwise or positive. At point 2 the flow direction is from 270° to 240°, and at point 3 the direction is from 300° to 270°, both of which are positive.
5. The difference in wind speed is taken over a predetermined interval normal to the streamline chord at each midpoint. The line along which the distance between isotachs is measured is placed on the isogon-isotach chart by use of the computational overlay, as shown in figure B.5. This may be accomplished also by measuring a normal distance of 75 miles (1¼' of latitude on either side of the midpoint).

   At point 1, the wind speed is decreasing in the positive n direction; thus the shear is negative. The sign of the term is entered on the worksheet as a positive number. If the computational overlay is used, the final sign is accounted for by the measurement, and the value is entered on the worksheet. At point 2, the sign of the shear along the positive n axis is negative, so ΔV is entered on the worksheet as a positive value. The same is also true for point 3.

($\zeta \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	$-\Delta V$ (m./sec.)	$\frac{-\Delta v}{\Delta n}$ (1/sec.)	ζ
1	100	30	+	+11		
2	60	25	+	+ 2		
3	180	30	+	+14		

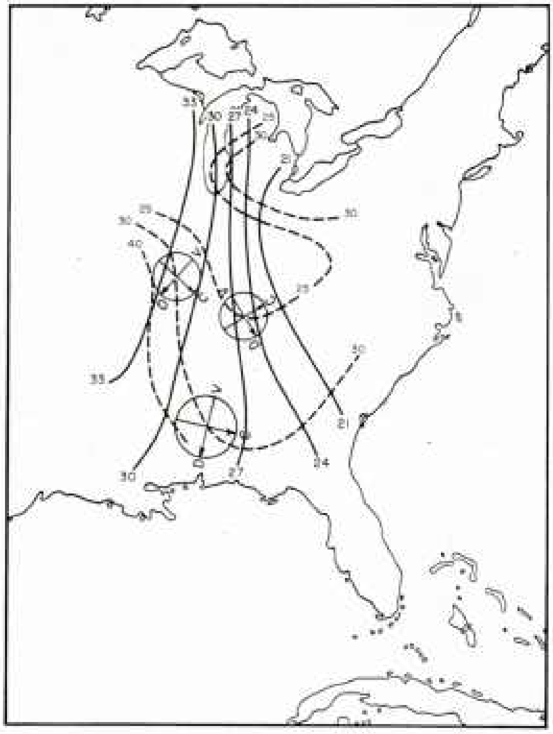

Figure B.5. Orientation of Radius Circles.

6. The $\frac{V}{R}$ table C.2 is entered using distance and velocity V for each computational point.

($\zeta \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	$-\Delta V$ (m./sec.)	$\frac{-\Delta v}{\Delta n}$ (1/sec.)	ζ
1	100	30	+ 8.01	+11		
2	60	25	+11.13	+ 2		
3	180	30	+ 4.45	+14		

7. Table 1 is used in the determination of $\frac{-\Delta v}{\Delta n}$ for an interval of $2\frac{1}{2}°$ or 150 nautical miles.

($\zeta \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	$-\Delta V$ (m./sec.)	$\frac{-\Delta v}{\Delta n}$ (1/sec.)	ζ
1	100	30	+ 8.01	+11	+3.96	
2	60	25	+11.13	+ 2	+0.72	
3	180	30	+ 4.45	+14	+5.05	

8. The two terms $\frac{V}{R}$ and $\frac{-\Delta v}{\Delta n}$ are added from table 1 to obtain the relative vorticity at points 1, 2 and 3.

($\zeta \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	$-\Delta V$ (m./sec.)	$\frac{-\Delta v}{\Delta n}$ (1/sec.)	ζ
1	100	30	+ 8.01	+11	+3.96	+11.97
2	60	25	+11.13	+ 2	+0.72	+11.85
3	180	30	+ 4.45	+14	+5.04	+ 9.50

9. The relative vorticity values are plotted for each point, and an analysis of the field is completed, as illustrated in figure B.6.

B.3 Example of Divergence Computations

For illustrative purposes, the orthogonal chords have been drawn as close to the streamline midpoints as possible. However, it is obvious that it becomes quite difficult on occasion to correlate the midpoints of both the streamline and the orthogonal chords. In practice, it is generally easier to use separate computation points for the relative vorticity and divergence computation.

Divergence calculation may be accomplished in the following steps:

1. A sheet of tracing paper is placed over the isogon-isotach analysis. The isogons are relabeled with their orthogonal values according to table A.1.

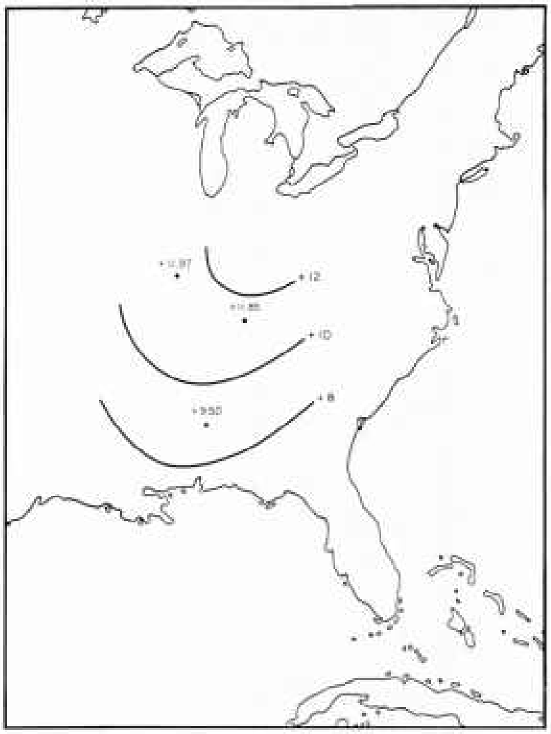

Figure B.6. Divergence Chart.

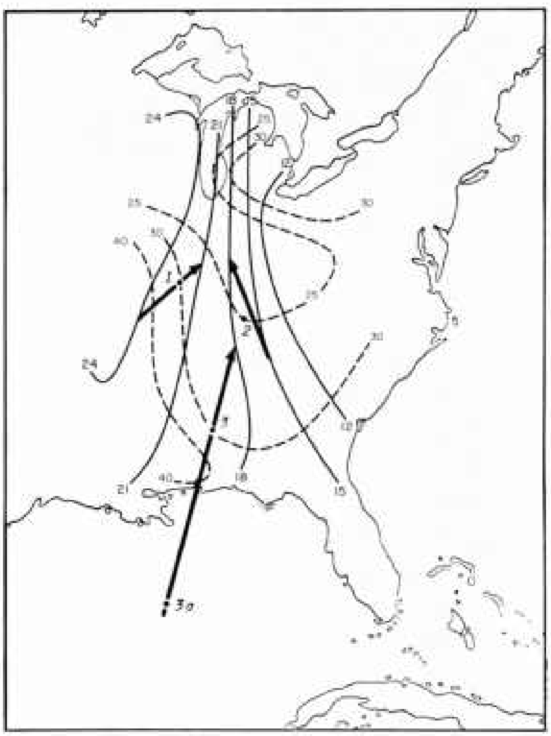

Figure B.7. Orientation of Orthogonal Chords.

2. The orthogonal chords arė drawn between isogons through the calculation points. At point 3, the midpoint of the orthogonal chord is approximately 400 nautical miles south of the computation point for relative vorticity. The midpoints are so far apart that a new computation point, 3a, is selected for the divergence calculation. Figure B.7 illustrates the orthogonal isogon values and the corresponding orthogonal chords for the three computation points.
3. Direction arrows are placed on the orthogonal chords in the direction of the orthogonal flow to aid in the sign determination to be performed at a later time.
4. The chordal distances and the midpoint speeds are entered on the divergence worksheet.

($D \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	$-\Delta V$ (m./sec.)	$\frac{-\Delta v}{\Delta n}$ (1/sec.)	D
1	220	30				
2	300	25				
3a	1000	20				

5. The sign of the curvature term is determined and entered on the worksheet for the three points. At point 1 the direction of the orthogonal flow is from 240° to 210°, which is cyclonic or positive. At point 2 the flow is from 150° to 180°, which is anticyclonic or negative. The flow at point 3 is from 210° to 180°, which is cyclonic and positive in sign.

($D \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	ΔV (m./sec.)	$\frac{\Delta v}{\Delta s}$ (1/sec.)	D
1	220	30	+			
2	300	25	-			
3a	1000	20	+			

6. The difference (ΔV) in wind speed is taken over predetermined intervals. For point 1, the wind speed is decreasing to the right of the orthogonal chord, indicating speed convergence and is negative. At point 2, the speed is also decreasing to the right of the orthogonal chord, so that the sign of ΔV is negative. At point 3a, the speed is increasing in the direction of the streamline flow, indicating speed divergence and a positive sign (fig. B.8).

($D \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	ΔV (m./sec.)	$\frac{\Delta v}{\Delta s}$ (1/sec.)	D
1	220	30	+	−7		
2	300	25	−	−2		
3a	1000	20	+	+1		

7. Using the chordal distance and the midpoint velocity for each computational point, the $\frac{V}{R}$ table C.2 is used to find the value of the directional term of the divergence equation.

($D \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	ΔV (m./sec.)	$\frac{\Delta v}{\Delta s}$ (1/sec.)	D
1	220	30	+3.64	−7		
2	300	25	−2.23	−2		
3a	1000	20	+0.53	+1		

8. The value of $\frac{\Delta v}{\Delta s}$, for an interval of 2½° latitude or 150 nautical miles, is determined by use of table 1.

($D \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	ΔV (m./sec.)	$\frac{\Delta v}{\Delta s}$ (1/sec.)	D
1	220	30	+3.64	−7	−2.52	
2	300	25	−2.23	−2	−0.72	
3a	1000	20	+0.53	+1	+0.36	

9. $\frac{V}{R}$ and $\frac{\Delta v}{\Delta s}$ are added to obtain the divergence for points 1, 2 and 3a.

($D \times 10^{-5}$ $sec.^{-1}$)

Pt.	Distance (naut. miles)	V (m./sec.)	$\frac{V}{R}$ (1/sec.)	ΔV (m./sec.)	$\frac{\Delta v}{\Delta s}$ (1/sec.)	D
1	220	30	+3.64	−7	−2.52	+1.12
2	300	25	−2.23	−2	−0.72	−2.95
3	1000	20	+0.53	+1	+0.36	+0.89

10. The divergence values are plotted at each computation point, and an analysis is made as illustrated in figure B.9.

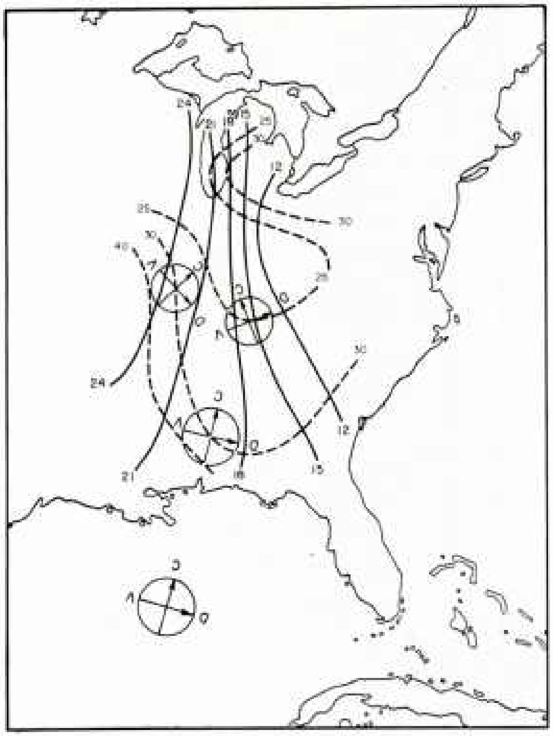

Figure B.8. Orientation of Orthogonal Radius Circles.

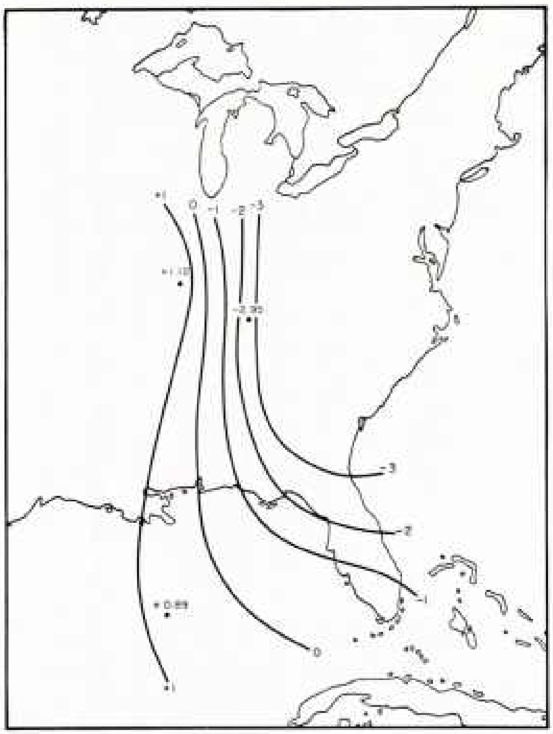

Figure B.9. Divergence Chart.

APPENDIX C
V/R COMPUTATION TABLES

Table C.1. V/R Computations (Knots)

DISTANCE(NM)	RADIUS(NM)	WIND SPEED(KNOTS)									
		1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
10.0	19.3	1.439	2.879	4.318	5.757	7.196	8.636	10.075	11.514	12.953	14.393
20.0	38.6	0.720	1.439	2.159	2.879	3.598	4.318	5.037	5.757	6.477	7.196
30.0	57.9	0.480	0.960	1.439	1.919	2.399	2.879	3.358	3.838	4.318	4.798
40.0	77.2	0.360	0.720	1.079	1.439	1.799	2.159	2.519	2.879	3.238	3.598
50.0	96.5	0.288	0.576	0.864	1.151	1.439	1.727	2.015	2.303	2.591	2.879
60.0	115.8	0.240	0.480	0.720	0.960	1.199	1.439	1.679	1.919	2.159	2.399
70.0	135.1	0.206	0.411	0.617	0.822	1.028	1.234	1.439	1.645	1.850	2.056
80.0	154.4	0.180	0.360	0.540	0.720	0.900	1.079	1.259	1.439	1.619	1.799
90.0	173.7	0.160	0.320	0.480	0.640	0.800	0.960	1.119	1.279	1.439	1.599
100.0	193.0	0.144	0.288	0.432	0.576	0.720	0.864	1.007	1.151	1.295	1.439
110.0	212.3	0.131	0.262	0.393	0.523	0.654	0.785	0.916	1.047	1.178	1.308
120.0	231.6	0.120	0.240	0.360	0.480	0.600	0.720	0.840	0.960	1.079	1.199
130.0	250.9	0.111	0.221	0.332	0.443	0.554	0.664	0.775	0.886	0.996	1.107
140.0	270.2	0.103	0.206	0.308	0.411	0.514	0.617	0.720	0.822	0.925	1.028
150.0	289.5	0.096	0.192	0.288	0.384	0.480	0.576	0.672	0.768	0.864	0.960
160.0	308.8	0.090	0.180	0.270	0.360	0.450	0.540	0.630	0.720	0.810	0.900
170.0	328.1	0.085	0.169	0.254	0.339	0.423	0.508	0.593	0.677	0.762	0.847
180.0	347.4	0.080	0.160	0.240	0.320	0.400	0.480	0.560	0.640	0.720	0.800
190.0	366.7	0.076	0.152	0.227	0.303	0.379	0.455	0.530	0.606	0.682	0.758
200.0	386.0	0.072	0.144	0.216	0.288	0.360	0.432	0.504	0.576	0.648	0.720
210.0	405.3	0.069	0.137	0.206	0.274	0.343	0.411	0.480	0.548	0.617	0.685
220.0	424.6	0.065	0.131	0.196	0.262	0.327	0.393	0.458	0.523	0.589	0.654
230.0	443.9	0.063	0.125	0.188	0.250	0.313	0.375	0.438	0.501	0.563	0.626
240.0	463.2	0.060	0.120	0.180	0.240	0.300	0.360	0.420	0.480	0.540	0.600
250.0	482.5	0.058	0.115	0.173	0.230	0.288	0.345	0.403	0.461	0.518	0.576

Table C.1. V/R Computations (Knots)

DISTANCE(NM)	RADIUS(NM)	WIND SPEED(KNOTS)									
		11.000	12.000	13.000	14.000	15.000	16.000	17.000	18.000	19.000	20.000
10.0	19.3	15.832	17.271	18.710	20.150	21.589	23.028	24.467	25.907	27.346	28.785
20.0	38.6	7.916	8.636	9.355	10.075	10.794	11.514	12.234	12.953	13.673	14.393
30.0	57.9	5.277	5.757	6.237	6.717	7.196	7.676	8.156	8.636	9.115	9.595
40.0	77.2	3.958	4.318	4.678	5.037	5.397	5.757	6.117	6.477	6.836	7.196
50.0	96.5	3.166	3.454	3.742	4.030	4.318	4.606	4.893	5.181	5.469	5.757
60.0	115.8	2.639	2.879	3.118	3.358	3.598	3.838	4.078	4.318	4.558	4.798
70.0	135.1	2.262	2.467	2.673	2.879	3.084	3.290	3.495	3.701	3.907	4.112
80.0	154.4	1.979	2.159	2.339	2.519	2.699	2.879	3.058	3.238	3.418	3.598
90.0	173.7	1.759	1.919	2.079	2.239	2.399	2.559	2.719	2.879	3.038	3.198
100.0	193.0	1.583	1.727	1.871	2.015	2.159	2.303	2.447	2.591	2.735	2.879
110.0	212.3	1.439	1.570	1.701	1.832	1.963	2.093	2.224	2.355	2.486	2.617
120.0	231.6	1.319	1.439	1.559	1.679	1.799	1.919	2.039	2.159	2.279	2.399
130.0	250.9	1.218	1.329	1.439	1.550	1.661	1.771	1.882	1.993	2.104	2.214
140.0	270.2	1.131	1.234	1.336	1.439	1.542	1.645	1.748	1.850	1.953	2.056
150.0	289.5	1.055	1.151	1.247	1.343	1.439	1.535	1.631	1.727	1.823	1.919
160.0	308.8	0.989	1.079	1.169	1.259	1.349	1.439	1.529	1.619	1.709	1.799
170.0	328.1	0.931	1.016	1.101	1.185	1.270	1.355	1.439	1.524	1.609	1.693
180.0	347.4	0.880	0.960	1.039	1.119	1.199	1.279	1.359	1.439	1.519	1.599
190.0	366.7	0.833	0.909	0.985	1.061	1.136	1.212	1.288	1.364	1.439	1.515
200.0	386.0	0.792	0.864	0.936	1.007	1.079	1.151	1.223	1.295	1.367	1.439
210.0	405.3	0.754	0.822	0.891	0.960	1.028	1.097	1.165	1.234	1.302	1.371
220.0	424.6	0.720	0.785	0.850	0.916	0.981	1.047	1.112	1.178	1.243	1.308
230.0	443.9	0.688	0.751	0.813	0.876	0.939	1.001	1.064	1.126	1.189	1.252
240.0	463.2	0.660	0.720	0.780	0.840	0.900	0.960	1.019	1.079	1.139	1.199
250.0	482.5	0.633	0.691	0.748	0.806	0.864	0.921	0.979	1.036	1.094	1.151

Table C.1. V/R Computations (Knots)

DISTANCE(NM)	RADIUS(NM)	WIND SPEED(KNOTS)									
		1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
260.0	501.8	0.055	0.111	0.166	0.221	0.277	0.332	0.387	0.443	0.498	0.554
270.0	521.1	0.053	0.107	0.160	0.213	0.267	0.320	0.373	0.426	0.480	0.533
280.0	540.4	0.051	0.103	0.154	0.206	0.257	0.308	0.360	0.411	0.463	0.514
290.0	559.7	0.050	0.099	0.149	0.199	0.248	0.298	0.347	0.397	0.447	0.496
300.0	579.0	0.048	0.096	0.144	0.192	0.240	0.288	0.336	0.384	0.432	0.480
310.0	598.3	0.046	0.093	0.139	0.186	0.232	0.279	0.325	0.371	0.418	0.464
320.0	617.6	0.045	0.090	0.135	0.180	0.225	0.270	0.315	0.360	0.405	0.450
330.0	636.9	0.044	0.087	0.131	0.174	0.218	0.262	0.305	0.349	0.393	0.436
340.0	656.2	0.042	0.085	0.127	0.169	0.212	0.254	0.296	0.339	0.381	0.423
350.0	675.5	0.041	0.082	0.123	0.164	0.206	0.247	0.288	0.329	0.370	0.411
360.0	694.8	0.040	0.080	0.120	0.160	0.200	0.240	0.280	0.320	0.360	0.400
370.0	714.1	0.039	0.078	0.117	0.156	0.194	0.233	0.272	0.311	0.350	0.389
380.0	733.4	0.038	0.076	0.114	0.152	0.189	0.227	0.265	0.303	0.341	0.379
390.0	752.7	0.037	0.074	0.111	0.148	0.185	0.221	0.258	0.295	0.332	0.369
400.0	772.0	0.036	0.072	0.108	0.144	0.180	0.216	0.252	0.288	0.324	0.360
410.0	791.3	0.035	0.070	0.105	0.140	0.176	0.211	0.246	0.281	0.316	0.351
420.0	810.6	0.034	0.069	0.103	0.137	0.171	0.206	0.240	0.274	0.308	0.343
430.0	829.9	0.033	0.067	0.100	0.134	0.167	0.201	0.234	0.268	0.301	0.335
440.0	849.2	0.033	0.065	0.098	0.131	0.164	0.196	0.229	0.262	0.294	0.327
450.0	868.5	0.032	0.064	0.096	0.128	0.160	0.192	0.224	0.256	0.288	0.320
460.0	887.8	0.031	0.063	0.094	0.125	0.156	0.188	0.219	0.250	0.282	0.313
470.0	907.1	0.031	0.061	0.092	0.122	0.153	0.184	0.214	0.245	0.276	0.306
480.0	926.4	0.030	0.060	0.090	0.120	0.150	0.180	0.210	0.240	0.270	0.300
490.0	945.7	0.029	0.059	0.088	0.117	0.147	0.176	0.206	0.235	0.264	0.294
500.0	965.0	0.029	0.058	0.086	0.115	0.144	0.173	0.201	0.230	0.259	0.288

Table C.1. V/R Computations (Knots)

DISTANCE(NM)	RADIUS(NM)	WIND SPEED(KNOTS)									
		11.000	12.000	13.000	14.000	15.000	16.000	17.000	18.000	19.000	20.000
260.0	501.8	0.609	0.664	0.720	0.775	0.830	0.886	0.941	0.996	1.052	1.107
270.0	521.1	0.586	0.640	0.693	0.746	0.800	0.853	0.906	0.960	1.013	1.066
280.0	540.4	0.565	0.617	0.668	0.720	0.771	0.822	0.874	0.925	0.977	1.028
290.0	559.7	0.546	0.596	0.645	0.695	0.744	0.794	0.844	0.893	0.943	0.993
300.0	579.0	0.528	0.576	0.624	0.672	0.720	0.768	0.816	0.864	0.912	0.960
310.0	598.3	0.511	0.557	0.604	0.650	0.696	0.743	0.789	0.836	0.882	0.929
320.0	617.6	0.495	0.540	0.585	0.630	0.675	0.720	0.765	0.810	0.855	0.900
330.0	636.9	0.480	0.523	0.567	0.611	0.654	0.698	0.741	0.785	0.829	0.872
340.0	656.2	0.466	0.508	0.550	0.593	0.635	0.677	0.720	0.762	0.804	0.847
350.0	675.5	0.452	0.493	0.535	0.576	0.617	0.658	0.699	0.740	0.781	0.822
360.0	694.8	0.440	0.480	0.520	0.560	0.600	0.640	0.680	0.720	0.760	0.800
370.0	714.1	0.428	0.467	0.506	0.545	0.583	0.622	0.661	0.700	0.739	0.778
380.0	733.4	0.417	0.455	0.492	0.530	0.568	0.606	0.644	0.682	0.720	0.758
390.0	752.7	0.406	0.443	0.480	0.517	0.554	0.590	0.627	0.664	0.701	0.738
400.0	772.0	0.396	0.432	0.468	0.504	0.540	0.576	0.612	0.648	0.684	0.720
410.0	791.3	0.386	0.421	0.456	0.491	0.527	0.562	0.597	0.632	0.667	0.702
420.0	810.6	0.377	0.411	0.445	0.480	0.514	0.548	0.583	0.617	0.651	0.685
430.0	829.9	0.368	0.402	0.435	0.469	0.502	0.536	0.569	0.602	0.636	0.669
440.0	849.2	0.360	0.393	0.425	0.458	0.491	0.523	0.556	0.589	0.621	0.654
450.0	868.5	0.352	0.384	0.416	0.448	0.480	0.512	0.544	0.576	0.608	0.640
460.0	887.8	0.344	0.375	0.407	0.438	0.469	0.501	0.532	0.563	0.594	0.626
470.0	907.1	0.337	0.367	0.398	0.429	0.459	0.490	0.521	0.551	0.582	0.612
480.0	926.4	0.330	0.360	0.390	0.420	0.450	0.480	0.510	0.540	0.570	0.600
490.0	945.7	0.323	0.352	0.382	0.411	0.441	0.470	0.499	0.529	0.558	0.587
500.0	965.0	0.317	0.345	0.374	0.403	0.432	0.461	0.489	0.518	0.547	0.576

Table C.2. V/R Computations (Meters per Second)

DISTANCE(NM)	RADIUS(NM)	WIND SPEED (MPS)									
		5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000
10.0	19.3	13.354	26.708	40.062	53.416	66.770	80.124	93.478	106.832	120.186	133.540
20.0	38.6	6.677	13.354	20.031	26.708	33.385	40.062	46.739	53.416	60.093	66.770
30.0	57.9	4.451	8.903	13.354	17.805	22.257	26.708	31.159	35.611	40.062	44.513
40.0	77.2	3.338	6.677	10.015	13.354	16.692	20.031	23.369	26.708	30.046	33.385
50.0	96.5	2.671	5.342	8.012	10.683	13.354	16.025	18.696	21.366	24.037	26.708
60.0	115.8	2.226	4.451	6.677	8.903	11.128	13.354	15.580	17.805	20.031	22.257
70.0	135.1	1.908	3.815	5.723	7.631	9.539	11.446	13.354	15.262	17.169	19.077
80.0	154.4	1.669	3.338	5.006	6.677	8.346	10.015	11.685	13.354	15.023	16.692
90.0	173.7	1.484	2.968	4.451	5.935	7.419	8.903	10.386	11.870	13.354	14.838
100.0	193.0	1.335	2.671	4.006	5.342	6.677	8.012	9.348	10.683	12.019	13.354
110.0	212.3	1.214	2.428	3.642	4.856	6.070	7.284	8.498	9.712	10.926	12.140
120.0	231.6	1.113	2.226	3.338	4.451	5.564	6.677	7.790	8.903	10.015	11.128
130.0	250.9	1.027	2.054	3.082	4.109	5.136	6.163	7.191	8.218	9.245	10.272
140.0	270.2	0.954	1.908	2.862	3.815	4.769	5.723	6.677	7.631	8.585	9.539
150.0	289.5	0.890	1.781	2.671	3.561	4.451	5.342	6.232	7.122	8.012	8.903
160.0	308.8	0.835	1.669	2.504	3.338	4.173	5.008	5.842	6.677	7.512	8.346
170.0	328.1	0.786	1.571	2.357	3.142	3.928	4.713	5.499	6.284	7.070	7.855
180.0	347.4	0.742	1.484	2.226	2.968	3.709	4.451	5.193	5.935	6.677	7.419
190.0	366.7	0.703	1.406	2.109	2.811	3.514	4.217	4.920	5.623	6.326	7.028
200.0	386.0	0.668	1.335	2.003	2.671	3.338	4.006	4.674	5.342	6.009	6.677
210.0	405.3	0.636	1.272	1.908	2.544	3.180	3.815	4.451	5.087	5.723	6.359
220.0	424.6	0.607	1.214	1.821	2.428	3.035	3.642	4.249	4.856	5.463	6.070
230.0	443.9	0.581	1.161	1.742	2.322	2.903	3.484	4.064	4.645	5.225	5.806
240.0	463.2	0.556	1.113	1.669	2.226	2.782	3.338	3.895	4.451	5.008	5.564
250.0	482.5	0.534	1.068	1.602	2.137	2.671	3.205	3.739	4.273	4.807	5.342

Table C.2. V/R Computations (Meters per Second)

DISTANCE(NM)	RADIUS(NM)	WIND SPEED (MPS)									
		5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000
260.0	501.8	0.514	1.027	1.541	2.054	2.568	3.082	3.595	4.109	4.623	5.136
270.0	521.1	0.495	0.989	1.484	1.978	2.473	2.968	3.462	3.957	4.451	4.946
280.0	540.4	0.477	0.954	1.431	1.908	2.385	2.862	3.338	3.815	4.292	4.769
290.0	559.7	0.460	0.921	1.381	1.842	2.302	2.763	3.223	3.684	4.144	4.605
300.0	579.0	0.445	0.890	1.335	1.781	2.226	2.671	3.116	3.561	4.006	4.451
310.0	598.3	0.431	0.862	1.292	1.723	2.154	2.585	3.015	3.446	3.877	4.308
320.0	617.6	0.417	0.835	1.252	1.669	2.087	2.504	2.921	3.338	3.756	4.173
330.0	636.9	0.405	0.809	1.214	1.619	2.023	2.428	2.833	3.237	3.642	4.047
340.0	656.2	0.393	0.786	1.178	1.571	1.964	2.357	2.749	3.142	3.535	3.928
350.0	675.5	0.382	0.763	1.145	1.526	1.908	2.289	2.671	3.052	3.434	3.815
360.0	694.8	0.371	0.742	1.113	1.484	1.855	2.226	2.597	2.968	3.338	3.709
370.0	714.1	0.361	0.722	1.083	1.444	1.805	2.166	2.526	2.887	3.248	3.609
380.0	733.4	0.351	0.703	1.054	1.406	1.757	2.109	2.460	2.811	3.163	3.514
390.0	752.7	0.342	0.685	1.027	1.370	1.712	2.054	2.397	2.739	3.082	3.424
400.0	772.0	0.334	0.668	1.002	1.335	1.669	2.003	2.337	2.671	3.005	3.338
410.0	791.3	0.326	0.651	0.977	1.303	1.629	1.954	2.280	2.606	2.931	3.257
420.0	810.6	0.318	0.636	0.954	1.272	1.590	1.908	2.226	2.544	2.862	3.180
430.0	829.9	0.311	0.621	0.932	1.242	1.553	1.863	2.174	2.484	2.795	3.106
440.0	849.2	0.303	0.607	0.910	1.214	1.517	1.821	2.124	2.428	2.731	3.035
450.0	868.5	0.297	0.594	0.890	1.187	1.484	1.781	2.077	2.374	2.671	2.968
460.0	887.8	0.290	0.581	0.871	1.161	1.452	1.742	2.032	2.322	2.613	2.903
470.0	907.1	0.284	0.568	0.852	1.137	1.421	1.705	1.989	2.273	2.557	2.841
480.0	926.4	0.278	0.556	0.835	1.113	1.391	1.669	1.947	2.226	2.504	2.782
490.0	945.7	0.273	0.545	0.818	1.090	1.363	1.635	1.908	2.180	2.453	2.725
500.0	965.0	0.267	0.534	0.801	1.068	1.335	1.602	1.870	2.137	2.404	2.671

Table C.2. V/R Computations (Meters per Second)

DISTANCE(NM)	RADIUS(NM)	WIND SPEED (MPS)									
		5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000
510.0	984.3	0.262	0.524	0.786	1.047	1.309	1.571	1.833	2.095	2.357	2.618
520.0	1003.6	0.257	0.514	0.770	1.027	1.284	1.541	1.798	2.054	2.311	2.568
530.0	1022.9	0.252	0.504	0.756	1.008	1.260	1.512	1.764	2.016	2.268	2.520
540.0	1042.2	0.247	0.495	0.742	0.989	1.236	1.484	1.731	1.978	2.226	2.473
550.0	1061.5	0.243	0.486	0.728	0.971	1.214	1.457	1.700	1.942	2.185	2.428
560.0	1080.8	0.238	0.477	0.715	0.954	1.192	1.431	1.669	1.908	2.146	2.385
570.0	1100.1	0.234	0.469	0.703	0.937	1.171	1.406	1.640	1.874	2.109	2.343
580.0	1119.4	0.230	0.460	0.691	0.921	1.151	1.381	1.612	1.842	2.072	2.302
590.0	1138.7	0.226	0.453	0.679	0.905	1.132	1.358	1.584	1.811	2.037	2.263
600.0	1158.0	0.223	0.445	0.668	0.890	1.113	1.335	1.558	1.781	2.003	2.226
610.0	1177.3	0.219	0.438	0.657	0.876	1.095	1.314	1.532	1.751	1.970	2.189
620.0	1196.6	0.215	0.431	0.646	0.862	1.077	1.292	1.508	1.723	1.938	2.154
630.0	1215.9	0.212	0.424	0.636	0.848	1.060	1.272	1.484	1.696	1.908	2.120
640.0	1235.2	0.209	0.417	0.626	0.835	1.043	1.252	1.461	1.669	1.878	2.087
650.0	1254.5	0.205	0.411	0.616	0.822	1.027	1.233	1.438	1.644	1.849	2.054
660.0	1273.8	0.202	0.405	0.607	0.809	1.012	1.214	1.416	1.619	1.821	2.023
670.0	1293.1	0.199	0.399	0.598	0.797	0.997	1.196	1.395	1.595	1.794	1.993
680.0	1312.4	0.196	0.393	0.589	0.786	0.982	1.178	1.375	1.571	1.767	1.964
690.0	1331.7	0.194	0.387	0.581	0.774	0.968	1.161	1.355	1.548	1.742	1.935
700.0	1351.0	0.191	0.382	0.572	0.763	0.954	1.145	1.335	1.526	1.717	1.908
710.0	1370.3	0.188	0.376	0.564	0.752	0.940	1.129	1.317	1.505	1.693	1.881
720.0	1389.6	0.185	0.371	0.556	0.742	0.927	1.113	1.298	1.484	1.669	1.855
730.0	1408.9	0.183	0.366	0.549	0.732	0.915	1.098	1.281	1.463	1.646	1.829
740.0	1428.2	0.180	0.361	0.541	0.722	0.902	1.083	1.263	1.444	1.624	1.805
750.0	1447.5	0.178	0.356	0.534	0.712	0.890	1.068	1.246	1.424	1.602	1.781

Table C.2. V/R Computations (Meters per Second)

DISTANCE(NM)	RADIUS(NM)	WIND SPEED (MPS) 5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000
760.0	1466.8	0.176	0.351	0.527	0.703	0.879	1.054	1.230	1.406	1.581	1.757
770.0	1486.1	0.173	0.347	0.520	0.694	0.867	1.041	1.214	1.387	1.561	1.734
780.0	1505.4	0.171	0.342	0.514	0.685	0.856	1.027	1.198	1.370	1.541	1.712
790.0	1524.7	0.169	0.338	0.507	0.676	0.845	1.014	1.183	1.352	1.521	1.690
800.0	1544.0	0.167	0.334	0.501	0.668	0.835	1.002	1.168	1.335	1.502	1.669
810.0	1563.3	0.165	0.330	0.495	0.659	0.824	0.989	1.154	1.319	1.484	1.649
820.0	1582.6	0.163	0.326	0.489	0.651	0.814	0.977	1.140	1.303	1.466	1.629
830.0	1601.9	0.161	0.322	0.483	0.644	0.804	0.965	1.126	1.287	1.448	1.609
840.0	1621.2	0.159	0.318	0.477	0.636	0.795	0.954	1.113	1.272	1.431	1.590
850.0	1640.5	0.157	0.314	0.471	0.628	0.786	0.943	1.100	1.257	1.414	1.571
860.0	1659.8	0.155	0.311	0.466	0.621	0.776	0.932	1.087	1.242	1.398	1.553
870.0	1679.1	0.153	0.307	0.460	0.614	0.767	0.921	1.074	1.228	1.381	1.535
880.0	1698.4	0.152	0.303	0.455	0.607	0.759	0.910	1.062	1.214	1.366	1.517
890.0	1717.7	0.150	0.300	0.450	0.600	0.750	0.900	1.050	1.200	1.350	1.500
900.0	1737.0	0.148	0.297	0.445	0.594	0.742	0.890	1.039	1.187	1.335	1.484
910.0	1756.3	0.147	0.293	0.440	0.587	0.734	0.880	1.027	1.174	1.321	1.467
920.0	1775.6	0.145	0.290	0.435	0.581	0.726	0.871	1.016	1.161	1.306	1.452
930.0	1794.9	0.144	0.287	0.431	0.574	0.718	0.862	1.005	1.149	1.292	1.436
940.0	1814.2	0.142	0.284	0.426	0.568	0.710	0.852	0.994	1.137	1.279	1.421
950.0	1833.5	0.141	0.281	0.422	0.562	0.703	0.843	0.984	1.125	1.265	1.406
960.0	1852.8	0.139	0.278	0.417	0.556	0.696	0.835	0.974	1.113	1.252	1.391
970.0	1872.1	0.138	0.275	0.413	0.551	0.688	0.826	0.964	1.101	1.239	1.377
980.0	1891.4	0.136	0.273	0.409	0.545	0.681	0.818	0.954	1.090	1.226	1.363
990.0	1910.7	0.135	0.270	0.405	0.540	0.674	0.809	0.944	1.079	1.214	1.349
1000.0	1930.0	0.134	0.267	0.401	0.534	0.668	0.801	0.935	1.068	1.202	1.335

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UNCLASSIFIED

This report was prepared as an aid to wind field analysis. A brief discussion of basic concepts in isogon-isotach analysis is followed by a discussion of methods for determining relative vorticity, divergence and vertical velocity.

Computation examples are included in the appendix.

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2. Wind Field Analysis
3. Isogon-Isotach Analysis
4. Vorticity
5. Divergence
6. Vertical Velocity

I. Title: The Use of Isogon-Isotach Charts for Determining Divergence, Relative Vorticity and Vertical Velocity

II. NWRF 13-0467-122
TASK 13

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